Activity 3 What Drives the Plates?

Goals

In this activity you will:

- Calculate the density of liquids and compare their densities with their position in a column of liquid.
- Observe the effects of temperature on the density of a material.
- Examine natural heat flow from within The Earth.
- Understand the results of uneven heating within The Earth.
- Understand the causes of the movement of lithospheric plates.

Think about It

Geoscientists are still uncertain about the most important forces that drive the plates.

- What causes the movement of the lithospheric plates?

What do you think? Record your ideas about this question in your *EarthComm* notebook. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: Effects of Density on the Position of Material

1. Obtain 30 mL each of water, pancake syrup, and vegetable oil. Suppose you were to carefully pour a small volume of each liquid into one graduated cylinder or clear tube.
   a) Predict what you think will happen. Sketch and explain your prediction.
2. One at a time, carefully pour 10 mL of each liquid into a cylinder or clear tube.
   a) Record your observations.
   b) Do your observations support your predictions?
   c) Does the order in which you pour the liquids make a difference in what you observe?
3. Develop a method to determine the density of each of the three liquids using a graduated cylinder, 10 mL of each liquid, and a balance scale. Density is mass per unit volume. Thus, the density of each liquid equals the mass of liquid (in grams) divided by the volume (10 mL).
   a) Write down your procedure for finding the density of each liquid.
   b) Make a data table to record your measurements and calculations for each liquid.
   c) After your teacher has approved your procedure, determine the density of each liquid.
4. Compare your calculations with your observations in **Step 2**.
   a) Describe how the densities you calculated explain what you observed.
   b) If layers of materials of different densities within the Earth behave like layers of liquids of different densities, what would you predict about the position of the rock layers of different densities in the Earth?

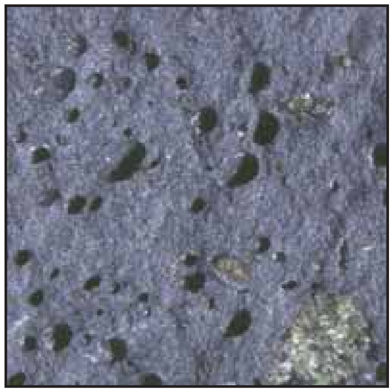
Part B: Effects of Temperature on Density of a Material

1. Place the bricks a few inches apart so the candle can slide between them. Pour about a 5 cm thick layer of corn syrup into a Pyrex® beaker or wide aluminum pan. Place the pan over the gap between the bricks. Light the candle and slide it under the center of the pan.
2. Place three pieces of balsa wood on the syrup.
   a) Predict what you think will happen to the wood as the corn syrup is heated. Record your ideas in your notebook.
3. Observe the wood. Record any changes every 5 min for 20 to 30 min.
   a) Use diagrams to record the changes you observe.
   b) Do your observations support your predictions? What do you think caused the results you observed?

Follow your teacher's safety advice about using a heat source. Hot corn syrup can cause burns. Clean up spills immediately.


sandstone


granite


basalt

Part C: Density of Earth Materials

1. Collect samples of rock from your community and also obtain samples of granite, basalt, and sandstone.
2. If you can, predict qualitatively the density of the samples. Which sample appears to be least dense? Which appears to be most dense?
   a) Record your predictions in your notebook.
3. Develop a method to find the density of each rock sample using the sample, water, a graduated cylinder, and a balance scale. Density is mass per unit volume. Thus, the density of each rock equals the mass of rock (in grams) divided by the volume of rock (in cubic centimeters). Note that 1 mL = 1 cm^3.
   a) Write down your procedure for finding the density of each rock sample.
   b) Make a data table to record your measurements and calculations for each rock.
   c) After your teacher has approved your procedure, determine the density of each rock sample.
4. Compare your calculations with your predictions.
   a) How does the density of the rock from your community compare with the densities of granite, sandstone, and basalt?

Part D: Forces Causing Subduction of Lithospheric Plates

1. Partly fill a large, rectangular tub with warm water. Wait until any tiny air bubbles have disappeared. The water has to be perfectly clear.
2. Very slowly and carefully, put a few ounces of liquid dish detergent in the water and mix it slowly and carefully with a mixing spoon. If any soap bubbles or foam remain on the water surface, scrape them off with a damp sponge.
3. Cut a piece of the vinyl plastic to be about six inches wide and about twelve inches long. Trim a flat, clear-plastic ruler with the scissors to be the same width as the plastic sheet. (The ruler should sink in water.) Tape the ruler to one end of the plastic sheet.
4. Dip the ruler end of the plastic sheet into the water to a depth of about 1 cm. Immediately place the plastic sheet on the water surface. Do this by holding the ends up, and letting the sagging middle part of the sheet touch the water surface first, to avoid trapping air bubbles under the sheet. Observe what happens. Repeat this step as many times as you need to make careful observations.
   a) Record your observations. Include a description of the motion of the plastic sheet in the water.
   b) What is the force that makes the plastic behave as it did?
   c) How does this demonstration show what happens in a subduction zone?

Reflecting on the Activity and the Challenge

You have seen evidence that liquids of varying densities will form layers in a container with the densest liquid on the bottom. You have also shown by modeling that a solid floating on a liquid seems to move away from a source of heat. You have seen evidence that different rocks are likely to have varying densities. Finally, you have made a direct observation of one of the main forces that cause subduction. These investigations will help you understand the Earth's interior and the flow of matter and energy in the Earth. You should now be able to explain why lithospheric plates can float and what might cause them to move.

Keep work area clean and dry.

Have paper towels ready for the wet plastic that is taken out of the tub.

Digging Deeper

THE EARTH'S INTERIOR STRUCTURE

Evidence for Earth's Layered Structure

Density (mass per unit volume) refers to how concentrated the mass (atoms and molecules) in an object or material is. Less dense material tends to rise upward and float on more dense material. Here are some everyday examples: a less dense solid floats in a more dense liquid; a more dense solid sinks to the bottom of a less dense liquid; a less dense liquid floats on a more dense liquid. Rocks in the Earth's crust (oceanic crust consists mainly of basalt; continental crust consists mainly of less dense rocks like granite) are less dense than the rocks of the underlying mantle. The crust "floats" on the more dense interior material.

Several kinds of evidence reveal that density varies within the Earth. Laboratory experiments in high-pressure apparatus show that rocks deep in the Earth are more dense than the same rocks when they are at the surface. The weight of the overlying rock puts pressure on rock below, making it more dense. The most dense material should be at the center of the Earth, where the pressure is greatest.

A second line of evidence comes from calculations of the average density of the Earth. You cannot put the Earth on a balance scale to find its mass, but the mass can be found indirectly using Newton's Law of Gravitation. According to that law, the gravitational force (F) between any two objects in the universe can be expressed this way:

$$F = \frac{g m_1 m_2}{d^2}$$

where m_1 and m_2 stand for the masses of two objects,

d stands for the distance between them, and

g stands for the gravitational constant (known from experiments).

Because the Earth exerts a certain force on a body (like you) with a certain mass m_1 on the Earth's surface, some 6400 km from its center, the known values can be substituted into the equation and the mass of the Earth (m_2) can be calculated. Dividing the mass of the Earth by its volume gives an average density of the Earth (in metric units) of 5.5 g/cm^3. The density of the rocks commonly found at the surface (granite, basalt, and sandstone) is much lower. The average density of surface rocks is 2.8 g/cm^3. The density of

Geo Words

density: the mass per unit volume of a material or substance.

Geo Words

core: the solid, innermost part of the Earth consisting mainly of iron.

the Earth's interior must be much greater than 2.8 g/cm^3 for the entire Earth to average 5.5 g/cm^3. This is partly due to the effect of compression, but also partly because the material in the Earth's core is mostly iron, which is much more dense than rocks, even when it is not under great pressure.

The speed of earthquake (seismic) waves within the Earth generated by earthquakes also provides convincing evidence about the properties of rock in the Earth. Scientists have learned that these waves travel faster the deeper they are in the Earth. It's known from laboratory experiments that earthquake (seismic) waves that travel at 4.8 km/s at the surface travel at 6.4 km/s at a depth of 1600 km. The reason why the speed of seismic waves increases downward in the mantle is complicated. In the laboratory, scientists use special equipment to measure the speeds of seismic waves in different rocks. They can determine how the speed of seismic waves changes with changes in temperature, pressure, and rock type.

Studies also show that change in density is not uniform with depth. Instead, there are distinct jumps or changes in density. By studying the changes in the speed of earthquake (seismic) waves as they pass through the Earth, scientists have concluded that the Earth's interior structure is layered. The thickness and the composition of the layers are shown in the table in *Figure 1*.

Layer	Thickness (km)	Composition	Temperature (°C)	Density (g/cm^3)
Continental crust	30–60	Granitic silicate rock (>60% silica)	20–600	~2.7
Oceanic crust	5–8	Basaltic silicate rock (<50% silica)	20–1300	~3.0
Mantle	2800	Solid silicate	100–3000	~5
Outer core	2150	Liquid iron-nickel	3000–6500	~12
Inner core	1230	Solid iron-nickel	7000	~12

Figure 1 The composition of the layers of the Earth.

Using the evidence they have observed, geoscientists divide Earth into four main layers: the inner **core**, the outer core, the mantle, and the **crust**, as shown in *Figure 2*. The core is composed mostly of iron. It is so hot that the outer core is molten. The inner core is also hot, but under such great pressure that it remains solid. Most of the Earth's mass is in the mantle. The mantle is composed of iron, magnesium, and aluminum silicate minerals. At over 1000°C, the mantle is solid rock, but it can deform slowly in a plastic manner. The crust is much thinner than any of the other layers, and is composed of the least dense rocks.

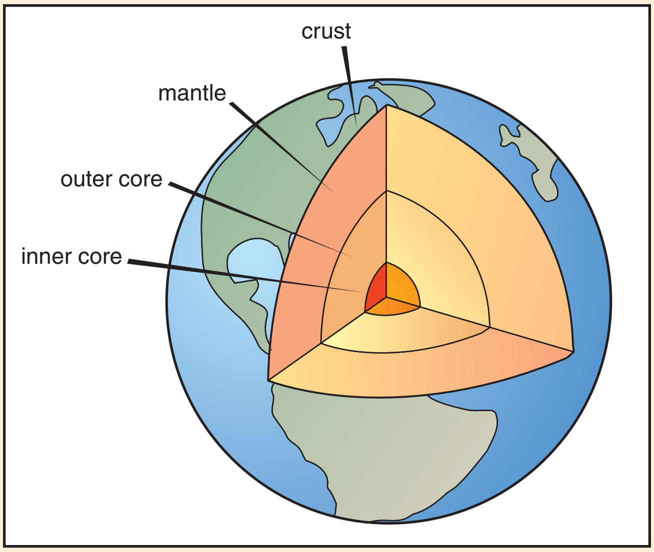


Figure 2 Schematic diagram showing the layered structure of the Earth's interior.

The Flow of Matter and Energy within the Earth

The temperature of the Earth increases with depth. This can be observed directly in mines and in oil wells. Sources of the Earth's internal heat include the decay of radioactive elements, the original heat of Earth's formation, and heating by the impact of meteorites early in Earth's history. The Earth can be thought of as a massive heat engine. The transfer of heat from Earth's interior to its surface drives the movements of the Earth's crust and mantle.

Temperature affects the density of materials. Hot-air balloons show this effect well. When the air inside a balloon is heated it expands (increases in volume). The mass of the balloon stays the same, but the volume increases. When the ratio of mass to volume drops, the density drops. Therefore, heating makes the balloon less dense than the surrounding air. The hot-air balloon begins to rise. Similarly, as rocks in the interior of the Earth are heated enough, their density decreases. The less dense rock rises slowly over time, unless the rocks are too rigid to allow flow.

In the activity, you heated corn syrup and observed the movement of balsa wood. Why did the balsa wood move? The answer lies in the process of **thermal convection**. Heating lowers the density of the corn syrup at the bottom of the container. This causes it to rise. As the corn syrup approaches the upper surface, it flows to the side, making room for more corn

Geo Words

thermal convection: a pattern of movement in a fluid caused by heating from below and cooling from above. Thermal convection transfers heat energy from the bottom of the convection cell to the top.

syrup rising from below. As it moves to the side, it cools. As it cools, it becomes more dense, and it sinks back to the bottom of the container. At the bottom of the container it is heated and rises again. This kind of density-driven circulation is called thermal convection, as shown in *Figure 3*. Thermal convection transfers heat energy from one place to another by the movement of material.

In 1929, the geologist Arthur Holmes elaborated on the idea that the mantle undergoes thermal convection. He suggested that this thermal convection is like a conveyor belt. He reasoned that rising mantle material can break a continent apart and then force the two parts of the broken continent in opposite directions. The continents would then be carried by the convection currents.

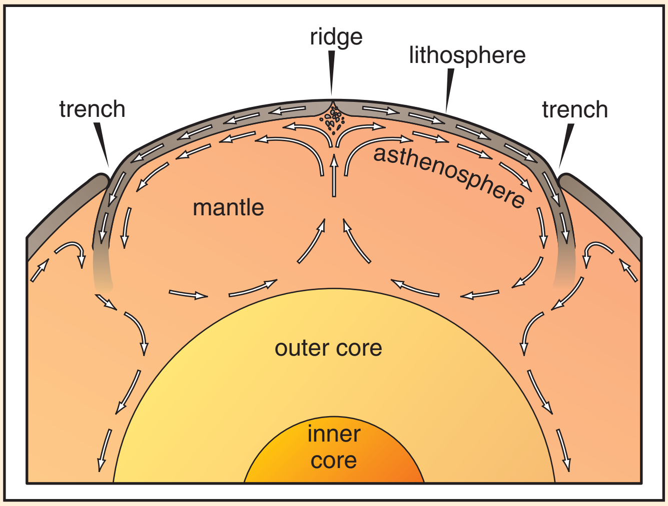


Figure 3 One possible pattern of thermal convection in the Earth's mantle. Convection cells like this might provide at least some of the driving force for the movement of lithospheric plates.

According to this hypothesis of mantle convection, material is heated at the core–mantle boundary. It rises upward, spreads out horizontally, cools, and sinks back into the interior. These extremely slow-moving convection cells might provide the driving force that moves the lithospheric plates (see *Figure 3*). Material rises to the surface at places where lithospheric plates spread apart from one another. Material sinks back into the Earth where plates converge. Although the idea was not widely appreciated during Holmes' time, mantle convection cells became instrumental in the development of the theory of plate tectonics.

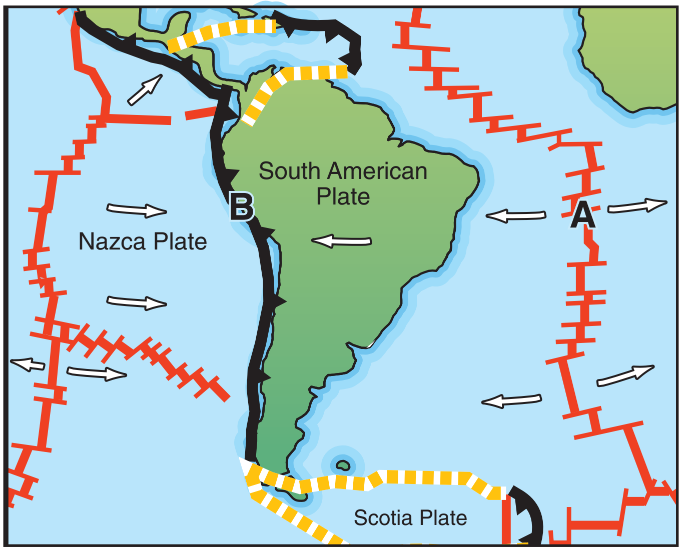
Mantle convection can't be observed directly, the way you could have observed convection in the corn syrup if you had put some tiny marker grains in the syrup. Geoscientists are sure that the mantle is convecting, but they are still unsure of the patterns of convection. The patterns probably don't look much like what is shown in *Figure 3*! Geoscientists now think that the lithospheric plates themselves play a major part in driving the convection, rather than just being passive riders on top of the convection cells. Do you remember from Activity 1 that the mid-ocean ridges are broad, and they slope gradually down to the deep ocean nearer the continents? That means that the plates on either side of the ridge crest slope downward away from the ridge crest, and they tend to slide downhill under the pull of gravity! In this way, they help the convection cell to keep moving, instead of the other way around. Also, you probably know that most materials expand when they are heated and shrink when they are cooled. As the plates in the ocean cool, they become more dense than the deeper mantle because they have almost the same composition but they are not as hot. They sink into the mantle of their own accord, just as in Part D of the investigation. In that way they help to keep the convection cell moving.

Check Your Understanding

1. How can the density of the Earth be calculated?
2. How does the density of the Earth provide evidence that the interior of the Earth is denser than the surface?
3. Name three main layers of the Earth.
4. Why is the inner core of the Earth solid, even though it is hot?
5. How are convection currents set up?
6. What part of the Earth's interior layers are in motion due to density differences?

Understanding and Applying What You Have Learned

1. Look at the map of lithospheric plates near South America and the relative "horizontal" motion between these plates.
   a) At point A, the two plates are moving away from each other. What is happening between them?
   b) At point B, two plates are moving toward each other. What happens as they continue to push toward each other if they have:
      (i) Different densities
      (ii) The same density



Map of the Nazca and South American plates.

2. Draw two pictures side by side. Make one the experiment with corn syrup and balsa wood. Make the other the Earth's interior structure. Show where heating and cooling occur, and use arrows to indicate the movement of material (the flow of matter and energy in both systems). Label the parts in each diagram and show how they correspond to each other.
3. What evidence is there at the Earth's surface for unequal heating somewhere within the Earth?
4. List some natural processes that occur when heat from the Earth's interior is transferred to the surface.
5. Use your understanding of density to calculate the missing values in the table below:

Object	Mass (g)	Volume (cm^3)	Density (g/cm^3)
Iron	41.8		7.6
Quartz	39.75	15.0	
Gold		8.0	19.3

Preparing for the Chapter Challenge

Reflect on your answers to the above. Write an essay that describes the Earth's interior structure and the flow of matter and energy within the Earth. Refer to the evidence you examined and the models you explored. Sketch and label a drawing or two to illustrate the main ideas. Be prepared to include this summary in your chapter report.

Inquiring Further

1. **Investigating Driving Forces for Plate Motions**

   What questions do you have about the driving forces behind plate tectonics? Develop a plan that would help you find an answer to one of your questions. Record your plan in your notebook. What further information might help you answer your questions?